Texas Higher Education Coordinating Board

Making Opportunity Affordable in Texas:

A Student-Centered Approach

Tuning of Chemistry

Texas Higher Education Coordinating Board

Austin, Texas

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Lumina Foundation for Education

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Tuning Oversight Council for Engineering and Science

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Definition of Tuning

"Tuning" is a faculty-led pilot project designed to define what students must know, understand, and be able to demonstrate after completing a degree in a specific field, and to provide an indication of the knowledge, skills, and abilities students should achieve prior to graduation at different levels along the educational pipeline – in other words, a body of knowledge and skills for an academic discipline in terms of outcomes and levels of achievement of its graduates.

Tuning provides an expected level of competency achievement at each step along the process of becoming a professional: expectations at the beginning of pre-professional study, at the beginning of professional study, and at the transition to practice. It involves seeking input from students, recent graduates, and employers to establish criterion-referenced learning outcomes and competencies by degree level and subject area. Through Tuning, students have a clear "picture" of what is expected and can efficiently plan their educational experience to achieve those expectations. The objective is not to standardize programs offered by different institutions, but to better establish the quality and relevance of degrees in various academic disciplines.

An overview of Lumina Foundation for Education's "Tuning USA" Initiative is available at: http://www.luminafoundation.org/goal_2025.html; an overview of Tuning work to date in Texas is available at: http://www.thecb.state.tx.us/tuningtexas.

Definition of Chemistry

Chemistry is the study of the properties, the composition, and the structure of matter, the physical and chemical changes it undergoes, and the energy liberated or absorbed during those changes.

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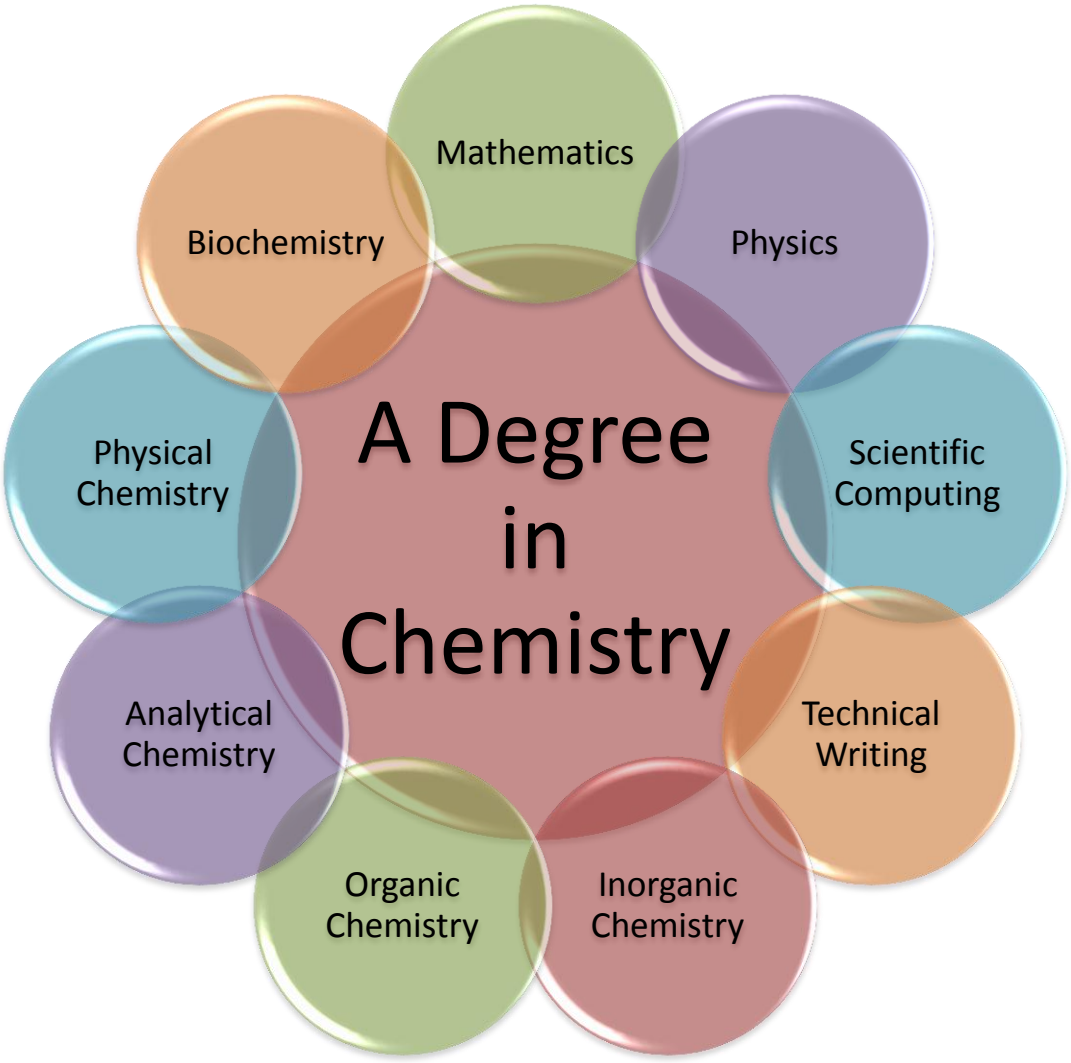
Chemistry Expertise Profile

The expertise profile lists types of course topics included in typical baccalaureate degrees in Chemistry. Note: General undergraduate degree requirements (e.g., the core curriculum) are not considered for the purpose of tuning Chemistry and this report.



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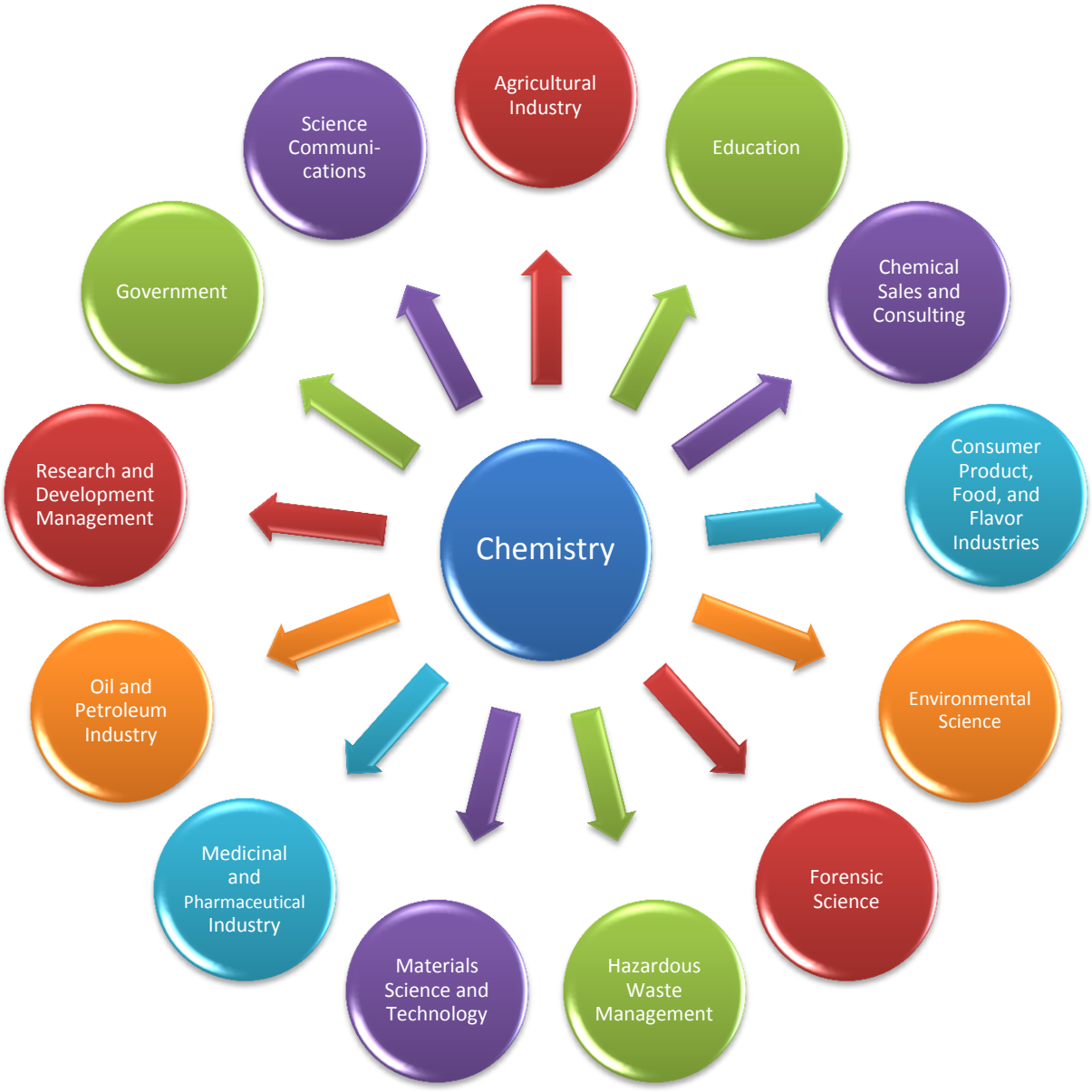
Chemistry Employment Profile

The employment profile lists employment opportunities available to Chemistry graduates.



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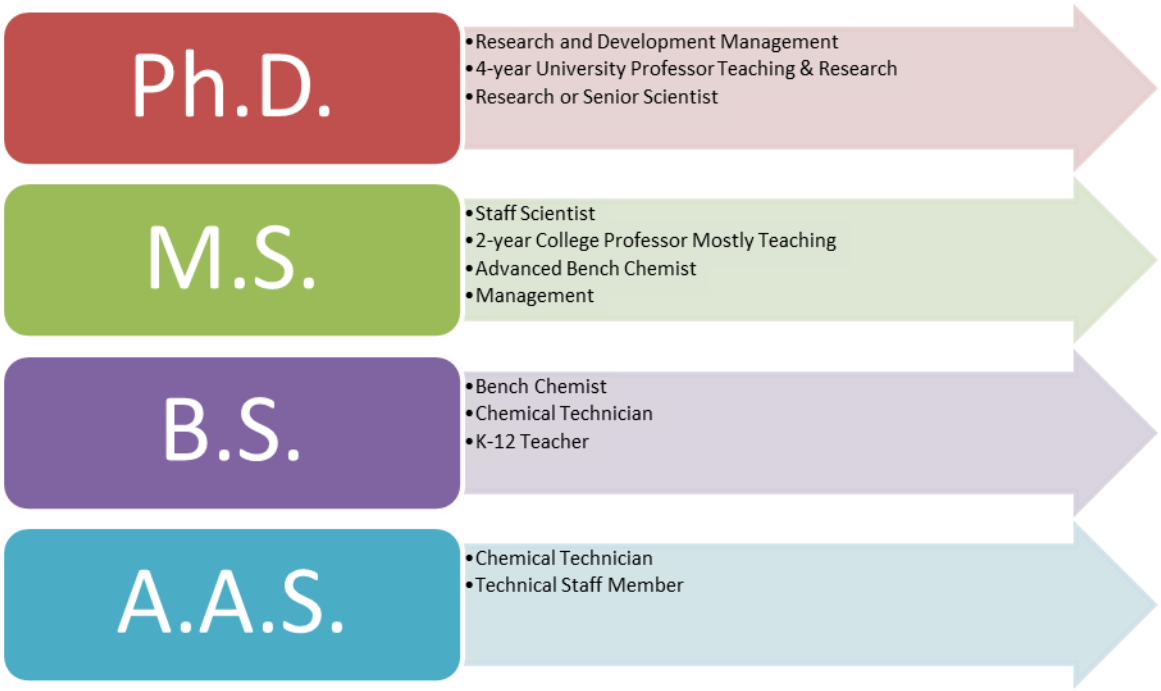
Degree Levels and Employment Levels



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Chemistry Key Competency Tables and Learning Outcome Descriptions

The chemistry competency table has 11 learning outcome titles, one for each learning outcome description:

1. Mathematics & Quantitative Reasoning
2. Scientific Computing
3. Laboratory Skills
4. Critical Thinking & Data Interpretation
5. Lifelong Learning
6. Professional/Ethical
7. Communication
8. Information Literacy
9. Teamwork
10. Research

The competency table has four learning outcome categories (columns from left to right):

1. core competencies needed to enter higher education in chemistry (HS)
2. competencies gained during first two years of chemistry study (CC)
3. baccalaureate-level chemistry competencies (BS)
4. graduate-level chemistry competencies (G)

Learning outcome descriptions for each of the outcome titles of the competency table explain the knowledge, skills, and attitudes that should be achieved by the graduates.

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Chemistry Key Competencies Diagram

Lumina Foundation Grant Chemistry Committee

	Math and Quantitative Reasoning	Scientific Computing	Laboratory Skills	Critical Thinking and Data Interpretation	Lifelong Learning	Professionalism and Ethics	Communication	Information Literacy	Teamwork	Research
Evaluation			G	G		G	G	G	G	G
Synthesis	G	G	BS	BS	G	G	BS	G	G	G
Analysis	BS	BS/G	BS	BS	G	G	BS	BS	BS	BS
Application	HS/CC	BS	CC	CC	BS	BS	CC	BS	CC	CC
Comprehension	HS/CC	BS	CC	CC	CC	CC	HS	CC	HS	CC
Knowledge	HS	CC	HS	HS	HS	HS / CC	HS	HS	HS	HS

G	graduate-level competencies
BS	baccalaureate-level competencies
CC	pre-Chemistry competencies gained during first two years of study
HS	secondary education competencies

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Mathematics & Quantitative Reasoning:

Mathematics is the science of numbers and their operations, interrelations, combinations, generalizations, and abstractions. The knowledge and problem-solving tools derived from the study of mathematics are essential to the understanding and the practice of chemistry.

The chemistry graduate should study the branches of mathematics essential to the practice of chemistry such as algebra, geometry, trigonometry, calculus.

Differential equations and/or statistics may be necessary for some branches of chemistry.

A successful chemist is able to apply mathematical specializations such as optimization, probability, random variables, group theory, numerical methods, vector analysis, linear algebra, and complex variables to chemical problems. Proficiency in multiple data graphing methods (i.e. scatter plotting, 2D and 3D graphing, Log-log plotting, etc.) is essential.

The chemist is able to interpret graphing methods mathematically (i.e., trend lines, linear regression, inverse relationships, etc.) as well as qualitatively (i.e., judging linearity, correlation, randomness, etc.). An understanding of the theories, strengths, and weaknesses of statistical data analysis is essential and some experience using statistical design of experiment tools is useful to the practicing chemist.

MATH AND QUANTITATIVE REASONING			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Solve basic problems in mathematics in algebra, geometry, trigonometry, and elementary statistics, and **apply** this knowledge to the solution of science and technology problems.	**Explain** key concepts and problem-solving processes in mathematics in algebra, geometry, trigonometry, calculus, and statistics. The chemist should further be able to **explain** concepts in data plotting and analysis methods.	**Solve** advanced problems in mathematics and **apply** this knowledge to the solution of chemistry problems. The chemist must be able to **apply** data plotting and analysis methods. **Analyze** a complex problem to determine the relevant mathematical and data plotting principles and then **apply** that knowledge to solve the problem.	**Evaluate** the reasonableness of quantitative studies done by others in peer-reviewed journals and one's own work.

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Scientific Computing:

Scientific computing, as it relates to chemistry, involves the use of computers to construct mathematical models and quantitative analysis techniques to solve chemical problems. These mathematical models range from the very simple linear least squares analysis to the highly complex modeling of a molecular geometry or crystal structure. Computer programs are being used in most chemical disciplines to calculate the chemical properties, structures, and physical properties of simple molecules, macromolecules, proteins, gases, liquids, and solids.

The successful chemistry graduate shall be able to utilize plotting programs, statistical packages, and spreadsheet applications to perform statistical evaluations, linear regression models, and data analysis. The chemistry graduate shall demonstrate knowledge of the traditional quantum mechanical systems (i.e., particle in a box, harmonic oscillator, rigid rotor, hydrogen atom, etc.). Chemists will be able to distinguish between the approximations made in the major computational algorithms of molecular mechanics, semi-empirical methods, density functional methods, and the various ab initio methods.

A successful chemist will also have experience computing molecular properties (i.e., molecular geometries, vibrational frequencies, internal energies, cLogP, etc.) using a variety of computational chemistry programs including newly developed internet-based applications. The graduate will also have the ability to write simple macros, scripts, and programs for processing text input and output files.

SCIENTIFIC COMPUTING			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Know how to calculate basic statistical evaluations such as average and standard deviation, and **know** how to produce and interpret basic charts and graphs by hand and by using a spreadsheet program.	**Identify** some of the properties of chemical substances commonly determined by computational chemistry software packages, and **recognize** some of their applicability to solving chemical problems.	**Discuss** and **distinguish** the similarities and differences between various computational techniques. **Conduct** computational studies to **generate** chemical information and to **identify** trends in properties.	**Create** simple macros, scripts, and programs to process chemical information, computer input and output files. **Analyze** and **compare** the results of computational chemistry studies.

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Laboratory Skills:

Laboratory skills are a critical component of chemical education. These skills, as they pertain to safely conducting experiments in a laboratory setting, are foundational to the chemical sciences.

Chemistry graduates must be able to conduct themselves in a safe manner while in a laboratory. This includes the knowledge of how to operate laboratory safety equipment such as the fume hood, emergency shower, eyewash station, first aid kit, fire extinguisher, and personal protective equipment. A chemist must also know how to research the properties and hazards of chemicals using Material Safety Data Sheets, practice proper chemical waste disposal procedures, and have an awareness of disposal regulations.

The chemistry graduate must have the ability to design and conduct experiments to address a specific question by using appropriate methodologies. Students shall develop the ability to analyze obtained results to determine if reasonable conclusions can be developed or an experimental redesign is required. Students must be able to recognize the inherent uncertainties of experimental measurements and the need to replicate the experimental protocol in an effort to achieve a high level of data reproducibility. A chemist must be able to accurately and clearly record experimental data using appropriate unit conventions in a laboratory notebook and maintain, organize, and communicate the data effectively to his/her peers.

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Laboratory training should include the synthesis of molecules and their isolation and characterization (via Column Chromatography, Polarimetry, Extraction, etc.) by safely using appropriate methods such as TLC, GC, HPLC, GC-MS, LC-MS, NMR, FT-IR, etc. The chemistry graduate should also study the properties of chemical systems by utilizing the appropriate methodologies and instrumental techniques. The chemistry graduate shall use effective technologies for handling electronic data records to ensure integrity of the experimental results.

LABORATORY SKILLS			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Identify safety procedures, safety equipment, and chemical hazards. **Name** common laboratory glassware and explain proper procedure for use.	**Demonstrate** the ability to work safely using hazardous chemicals; **apply** appropriate lab techniques; **utilize** laboratory equipment, glassware, and instrumentation to gather data.	**Design** and **conduct** experiments to address a specific question by **using** appropriate methodologies. **Organize, analyze, draw conclusions,** and **communicate** data collected.	**Evaluate** experimental protocols and **assess** data to determine if reasonable conclusions can be drawn or experimental redesign is required. **Optimize** experimental protocol to obtain relevant data.

Critical Thinking & Data Interpretation:

Critical thinking is often associated with higher-order thinking skills and includes such actions as developing hypotheses, alternative ways of viewing a problem, questions, possible solutions, and plans for investigation.

Critical thinking usually requires the student to do some or all of the following; recognize central issues and assumptions in an argument, identify important relationships, make correct inferences from data, deduce conclusions from information or data provided, determine whether conclusions are warranted on the basis of the data given, and evaluate evidence.

The chemistry graduate shall use creativity and insight to recognize and describe patterns associated with chemical phenomena, relying on reproducible observations of empirical evidence when constructing, analyzing, and evaluating explanations of chemical processes. It is essential that a chemist be able to utilize skepticism and logic in chemical investigations; analyze the difference between fact and opinion; apply rules of procedure, methods, ideas, or theories in various situations; identify patterns; evaluate feasibility; and provide solutions to problems using broad and in-depth analysis from interdisciplinary perspectives.

A chemistry graduate must be capable of conveying chemical information to others using appropriate forms of communication. A chemist is also rational and critical when analyzing and interpreting scientific claims within various forms of communication.

The successful chemist formulates appropriate questions, develops experimental procedures, proposes plans of operation, and formulates abstract relations to classify data or explain chemical phenomena.

Experimental data are used by the chemist to guide experimental redesign. Experimental results are used to find solutions to chemical problems. When evaluating materials or methods, the chemistry graduate should be able to make quantitative and qualitative judgments about the degree to which given or developed criteria are satisfied.

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CRITICAL THINKING AND DATA INTERPRETATION			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Recognize central issues and assumptions in an argument. **Identify** important relationships. **Recognize** patterns associated with chemical phenomena.	**Make** correct inferences from data. **Apply** rules of procedure, methods, ideas, or theories in various situations. **Convey** chemical information to others using appropriate forms of communication.	**Formulate** appropriate questions, **develop** experimental procedures, **propose** a plan of operation, and **formulate** abstract relations to classify data or explain chemical phenomena. **Determine** whether conclusions are warranted on the basis of data. **Parse** the difference between fact and opinion. **Use** experimental data to guide experimental redesign.	**Make** quantitative and qualitative **judgments** about the degree to which given or developed criteria are satisfied when **evaluating** materials or methods. **Evaluate** experimental evidence. **Judge** explanations of chemical processes.

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Lifelong Learning:

Lifelong learning is the process of gaining knowledge and skills gradually and continuously throughout life whether by formal education or through informal experiences.

As students "learn how to learn" while in school and acquire knowledge of how chemists develop professionally they will hopefully continue to foster and appreciate the lifelong quest for knowledge.

Scientific knowledge is not static, but grows as new discoveries are made and new ways of describing phenomena are developed. Therefore, chemistry programs must emphasize the importance of lifelong learning in an effort to demonstrate to the student that continuous professional and intellectual development has a profound impact on the longevity, productivity, and trajectories of a career. The roles of formal education, professional experience (including networking), and informal learning (conferences, seminars, magazines, journals, etc.) should be developed. Furthermore, with the evolving nature of the chemistry discipline, the successful chemistry graduate should recognize the need and develop an appreciation for lifelong learning as a professional and ethical responsibility for ensuring competence and protecting the environment.

LIFELONG LEARNING			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Identify techniques that may enhance student achievement in collegiate studies. **Identify** ways that researchers and other professionals relate information to each other and the general public.	**Describe** and **select** suitable learning strategies to enhance student success. **Recognize** the various ways chemists participate in professional development.	**Recognize** the evolving nature of the chemistry discipline. **Use** professional development opportunities to further one's knowledge in the field.	**Examine** information in communications (papers, seminars, conferences) in order to gain new knowledge. **Develop** the necessary skills that will enable one to progress in and contribute to the discipline. **Evaluate** one's own personal and professional growth.

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Professionalism and Ethics:

Ethics - within the framework of chemistry - refers to the use of moral principles to guide an objective approach to making decisions, answering questions, and communicating findings to peers and the general public. This includes maintaining the integrity of the scientific process, showing moral courage when confronted with ethical dilemmas, and acting as stewards of the local and global community.

Chemistry programs must demonstrate to their students that, as a science that seeks truth, chemistry is an endeavor based on trust. In general, the chemistry graduate should be able to recognize questionable ethics within the chemical discipline, and have the foresight to act according to professional codes of conduct (such as the American Chemical Society's Chemical Professional's Code of Conduct) to earn the trust of their peers and the general public. Therefore, it is essential that chemistry students be exposed to the idea of academic and scientific integrity and the consequences of data falsification, fabrication, and plagiarism; all of which undermine the learning process and erode the credibility of the professional chemist. The successful chemistry graduate should have an understanding of the importance of the peer review process as a mechanism to ensure not only experimental novelty, but also the authenticity and reproducibility of data. Additionally, the chemistry graduate should have some knowledge of the laws that define various aspects of intellectual property that are relevant to the chemical discipline.

PROFESSIONALISM AND ETHICS			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Recognize and **demonstrate** the importance of ethics and ethical behavior.	**Identify, comply with,** and **demonstrate** appropriate professional and ethical behaviors.	**Apply** lessons learned from the professional and ethical behaviors of self and others to **discern** the appropriate behaviors.	**Analyze and comply with** professional and ethical standards of behavior to **execute** appropriate behaviors. **Anticipate** areas of ethical concern and exercise **self-assessment** with regard to professional and ethical concerns.

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Communication:

Written communication involves the drafting of both technical and non-technical documents commonly encountered in chemistry (i.e. lab records, reports, project proposals, peer-reviewed articles, and experimental protocols). Often technical documents must adhere to a standard format such as the ACS Style Guide. Visual communication involves conveying information by use of graphics, images, and video. Oral communication involves the ability to successfully convey ideas through speech during meetings, presentations, and conferences.

The successful chemistry graduate must have the ability to clearly communicate ideas through a variety of mediums. A chemist must demonstrate clear and effective written, visual, and oral communication skills.

COMMUNICATION			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Describe and **produce** a wide variety of information using different forms of communication.	**Produce** different types of communication such as lab records, reports, papers, posters, and oral presentations.	**Develop** various forms of organized communication of original work. **Examine** the communication of others.	**Appraise** the value of different types of communication. **Select** effective communication modes. **Assess** the communication of others in both oral and written form, including peer-reviewed journals.

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Information Literacy:

Information literacy refers to the ability to locate, collect, analyze, and process relevant information within a discipline or between related fields. The distinction between primary and secondary sources versus hearsay information is emphasized.

The chemistry graduate shall identify primary sources of information and have the ability to scrutinize content - especially material posted online - as reliable or unreliable. The collection of relevant information from the primary literature is essential for contextualization of contemporary issues in chemistry. The successful chemistry graduate will have the ability to use acceptable standards of citing literature from a variety of sources, and should be familiar with scientific databases (Chemical Abstracting Service, Web of Knowledge, Science Direct, etc.) for locating relevant research articles published worldwide in the field of chemistry. The chemistry graduate will also need to effectively utilize the vast amount of reference data available in chemical handbooks, on government websites, on chemically specific internet search tools, and the internet in general.

INFORMATION LITERACY			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Describe the importance of proper citation. **Identify** plagiarism.	**Distinguish** reliable resources from hearsay. **Summarize** the contents of resources and cite appropriately.	**Conduct** and **analyze** a literature review using the chemical literature databases and chemical journals. **Characterize** the strengths and weaknesses of different informational resources.	**Plan** a Literature Review. **Critically evaluate** the contents of resources and **integrate** the information in a novel context. **Justify** methods based on related works.

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Teamwork:

Teamwork skills are those skills which allow the trained scientist to work with individuals from any background in the team setting. These skills include familiarity with the terminology and jargon of the other team members, as well as "soft skills" necessary to maximize productivity while working with individuals who have varying levels of skill and motivation.

Chemistry majors must demonstrate an understanding and appreciation for the other various fields of study within the science, technology, engineering, and mathematics (STEM) landscape. Such an understanding enables chemists to function on multidisciplinary committees or teams that address problems spanning a spectrum of science specialties. Chemistry majors should develop skill sets that allow the interaction with both science and non-science team members.

Functioning as part of a multidisciplinary team requires the chemist to communicate effectively with people who possess different skill sets and backgrounds. Therefore, chemistry programs should emphasize skills involving leadership, organization, and conflict resolution, as well as those skills that promote harmony in a multidisciplinary team and that encourage productivity and professionalism.

TEAMWORK			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Demonstrate an appreciation for the importance of teamwork. **Recognize** and describe the various STEM fields that must work together to solve problems in modern society.	**Apply** effective team building skills. **Contribute** to a team project and report.	**Analyze** input from both scientific and non-scientific disciplines **identifying** the strengths of having multiple points of view.	**Organize** and/or **facilitate** team efforts applied to solving problems. **Assess** the input from team members **providing constructive critical** feedback to team members.

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Research:

Research can be defined as an inquiry-based scientific approach leading to the discovery of new ideas or finding solutions to existing problems.

Research experiences involve an immersion of the chemistry student in a research setting with the departmental faculty or an internship. The chemistry graduate should demonstrate the ability to design a research project, develop experimental protocols, collect and interpret relevant data, and communicate results. To demonstrate a thorough understanding of the research project, students should be required to present their findings, either as a written report or presentation. This report or presentation should also include suggested future experimental approaches and studies. The chemistry program should strive to provide exposure to the latest aspects of chemical research through various means such as seminar programs and scientific society meetings.

Chemists should progress in research to the point of becoming self-directed, independent contributors who develop original research proposals; design research plans; evaluate their own work as well as the work of others; and defend the approach and conclusions of a particular research project, study, or set of experiments.

RESEARCH			
Core Competencies Needed to enter Higher Education in Chemistry	**Competencies gained during first two years of Chemistry study**	**Baccalaureate-Level Chemistry Competencies**	**Post-Graduate/ Work Experience Chemistry Competencies**
Describe the scientific method and the principles of systematic scientific inquiry.	**Conduct** planned experiments and discuss findings orally and in written form along with a summary evaluation of the quality of the results.	**Participate** in a research experience where protocols are **formulated,** data is **collected,** results are **analyzed,** and future work is **proposed.**	**Plan** and **execute** an independent research project. **Complete, present, appraise,** and **defend** the research findings to a group of scientists.

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Community College Program of Study for Transfer to a Chemistry Program

FRESHMAN YEAR

First Semester (Fall)		Second Semester (Spring)	
Course	SCH	Course	SCH
MATH 2413 Calculus I	4	MATH 2414 Calculus II	4
CHEM 1311 General Chemistry I	3	CHEM 1312 General Chemistry II	3
CHEM 1111 General Chemistry I lab	1	CHEM 1112 General Chemistry II lab	1
XXXX #### Texas Core Curriculum Requirement	2	XXXX #### Texas Core Curriculum Requirement	3
XXXX #### Texas Core Curriculum Requirement	3	XXXX #### Texas Core Curriculum Requirement	3
XXXX #### Texas Core Curriculum Requirement	3	XXXX #### Texas Core Curriculum Requirement	3
Semester Credit Hours	16	Semester Credit Hours	17

SOPHOMORE YEAR

First Semester (Fall)		Second Semester (Spring)	
Course	SCH	Course	SCH
CHEM 2323 Organic Chemistry I	3	CHEM 2325 Organic Chemistry II	3
CHEM 2123 Organic Chemistry I lab	1	CHEM 2125 Organic Chemistry II lab	1
PHYS 2325 University Physics I	3	PHYS 2326 University Physics II	3
PHYS 2125 University Physics I lab	1	PHYS 2126 University Physics II lab	1
XXXX #### Texas Core Curriculum Requirement	3	XXXX #### Texas Core Curriculum Requirement	3
XXXX #### Texas Core Curriculum Requirement	3	XXXX #### Texas Core Curriculum Requirement	3
Semester Credit Hours	14	Semester Credit Hours	14

Notes:

1 Texas Common Course Numbers are used for all TCCN-numbered courses.

2 The student is encouraged to check with the institution to which he/she plans to attend for transferability conditions for CHEM 2325/2125 Organic Chemistry II and its accompanying lab.

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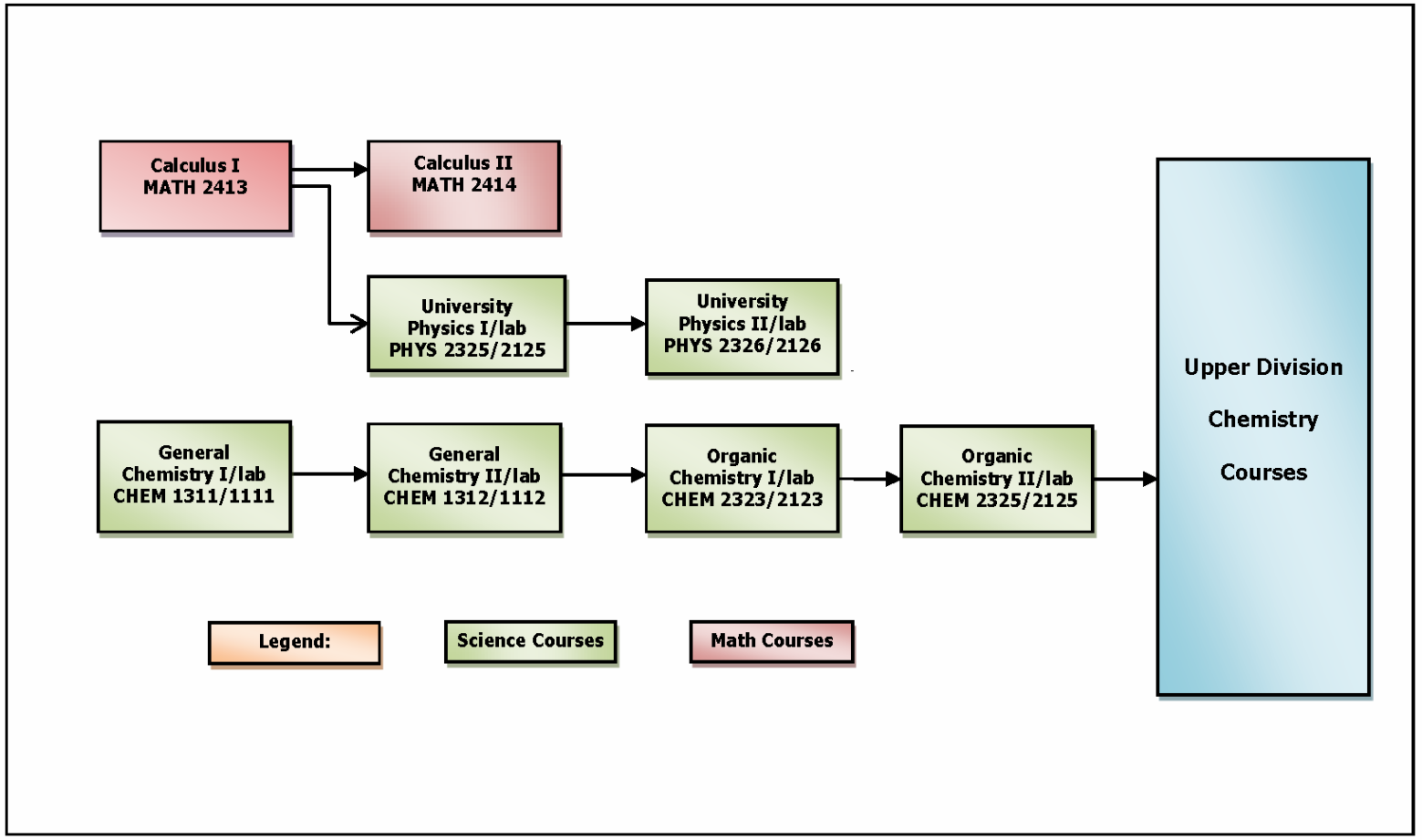
Community College Prerequisite Flowchart for Chemistry



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Resources

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